Dual-use Cosmo/Skymed Data for the Monitoring of Coastal Areas: Azimuth Ambiguity Filtering

Gerardo Di Martino, Antonio Iodice, Daniele Riccio, Giuseppe Ruello

Università degli Studi di Napoli "Federico II", DIETI,
Via Claudio 21, I-80125 Napoli, Italy.
E-mail: gerardo.dimartino@unina.it; iodice@unina.it; daniele.riccio@unina.it; ruello@unina.it

Abstract - **Cosmo/Skymed is a constellation of X-band high-resolution spaceborne Synthetic Aperture Radar (SAR) sensors launched and operated by the Italian Space Agency. It was designed, and is currently employed, as a dual-use system. Within this framework, coastal monitoring and ship detection by using SAR data is of fundamental importance for both military and civilian uses. However, SAR data, and in particular Cosmo/Skymed data, of coastal areas are often affected by azimuth ambiguity effects, which cause the appearance on the image of "ghosts" of brilliant targets that can be erroneously interpreted as real targets (ships, in the ship-detection case). Therefore, for coastal areas monitoring and ship detection, use of azimuth ambiguity reduction techniques is mandatory.**

In the following, we consider an azimuth ambiguity filtering method that we recently developed and we apply it as a preliminary step for coastal area monitoring. Some criteria to judge the effectiveness of the method are devised and employed to Cosmo/Skymed data relative to the Gulf of Naples (Italy) and Malta coastal areas.

Index Terms— Synthetic Aperture Radar, ship detection, azimuth ambiguity, Wiener filtering.

I. INTRODUCTION

Thanks to the current wide availability of Synthetic Aperture Radar (SAR) data from high and medium resolution sensors (Cosmo/SkyMed, TerraSAR-X, Sentinel-1, Radarsat-2) with low revisit time, monitoring coastal areas by using SAR images is gaining increasing interest. In particular, SAR-based ship detection methods are of great relevance for both military (for instance, in the control of hostile ships) and civilian (fishery control, immigration flux monitoring, etc.). Accordingly, dual-use Italian Cosmo/Skymed SAR constellation is an ideal tool for this family of methods. However, available standard SAR images of coastal areas often cannot be used as they are, because they are subject to the well-known azimuth ambiguity problem [1]-[2], caused by the use of a finite pulse repetition frequency (PRF) and of a non-ideal azimuth antenna pattern (AAP). Due to this effect, on SAR images replicas (or "ghosts") of brilliant points or areas appear, that are shifted both in azimuth and (although in a smaller extent) in range. These replicas are strongly attenuated, due to the azimuth antenna beam pattern and because they are not well focused. However, if "ghosts" of high-reflectivity targets (for instance, buildings on the coast) are placed in a low-scattering area (such as the sea surface), they emerge with respect to the background and can be erroneously interpreted as actual targets. This may cause serious image interpretation errors: for instance, for ship-detection applications, these ghosts may cause false alarms; or, in automatic coastline extraction, coastlines of false islands can be detected and extracted. Therefore, for coastal areas monitoring, use of azimuth ambiguity reduction techniques is mandatory.

In the following, we consider an azimuth ambiguity filtering method that we recently developed [2] and we apply it as a preliminary step for coastal area monitoring: some criteria to judge the effectiveness of the method are devised and employed, as illustrated in the following. Of course, the same presented criteria can be used for other azimuth ambiguity reduction methods.

II. AZIMUTH FILTERING METHOD

The considered azimuth filtering method, that we called "asymmetric mapping and selective filtering" (AM&SF), is based on the theory of selective filtering and on a two-step procedure. In the first step, two asymmetric filters are used to suppress ambiguities due to each sidelobe of the antenna pattern, and the ratios between the original and filtered images are used to produce two binary maps of the ambiguity-affected areas (one for each sidelobe). The transfer function of the filters is obtained using the theory of Wiener filtering, as in [3]: substantially, in the frequency domain each filter selects the region of the signal spectrum less affected by aliasing, i.e., the region where the null of the considered folded AAP sidelobe is located (in fact, the azimuth spectrum of the scene reflectivity is weighted by the AAP of the sensor, so that where the folded AAP presents a null, the spectrum of the ambiguity will be null, whatever the original shape of reflectivity spectrum). Use of two different filters and, hence, two different maps (one for each first sidelobe) for ghost detection, differently from [3], allows identification of ghosts even in cases in which the AAP and PRF value are such that the peak of one folded AAP sidelobe locates almost exactly in correspondence of the null of the other one. This is sometime the case for current high resolution spaceborne SAR sensors, e.g. TerraSAR-X and Cosmo/SkyMed. In the second step, the binary maps of the ambiguity-affected areas are used to produce a final image in which only the areas affected by the ambiguities are replaced by their filtered versions, obtained via the proper of the two filters cited above.

A block scheme of the AM&SF algorithm is reported in Fig.1.

III. Experimental results

Here we propose two "measures" of the effectiveness of the method: the first one is the reduction of the false-alarm rate in ship detection applied to filtered images; a standard CFAR method [4] is considered to this purpose. The second one is the "confusion matrix" of a two-class classification (land/sea) used as the preliminary step of a coastline extraction algorithm.

Performance of the considered technique in terms of above presented criteria are evaluated with reference to Cosmo/Skymed data relative to the Gulf of Naples (Italy) and Malta coastal areas. In particular, in the following we focus on the reduction of the false-alarm rate in ship detection, and defer the full analysis, including the coastline detection algorithm performance, to the conference presentation.

In particular, let us consider the Cosmo/Skymed SAR image, acquired in the stripmap mode (resolution is about 3 m in this acquisition mode), displayed Fig. 2(a): over the sea surface area, several "ghosts", i.e., replicas of high reflectivity objects placed on the land (most likely large buildings) are clearly visible. In Fig. 2(b) we show the same image after the filtering of azimuth ambiguity via our AM&SF algorithm: it can be appreciated that the ambiguity effect has been drastically reduced, and "ghosts" have disappeared.

In order to move to a more quantitative analysis, we apply a standard CFAR algorithm [4] for ship detection to both unfiltered and filtered images. In Fig. 2(c) we show a full-resolution enlarged portion of the unfiltered image of Fig.2(a), in which the "ships" identified by the CFAR algorithm are highlighted by red rectangles. Actually, this image consists of an actual ship, correctly identified by the CFAR ship detection algorithm, surrounded by a large number of "ghosts" due to azimuth ambiguity, eleven of which are erroneously detected as "ships" by the CFAR ship detection algorithm.

The same full-resolution portion of the filtered image of Fig. 2(b) is displayed in Fig. 2(d), and the ship identified by the CFAR algorithm is highlighted by a red rectangle. We can appreciate in Fig. 2(d) how, after filtering, the "ghosts" due to azimuth ambiguity are strongly attenuated, so that only the actual ship is correctly identified by the CFAR ship detection algorithm, and no false alarms are present.

As a second example, let us consider the Cosmo/Skymed SAR image, again acquired in the stripmap mode (resolution is about 3 m in this acquisition mode) depicted in Fig. 3. This scene contains several ships and little boats over a low-wind sea area. This time, some ghosts appear due to the most brilliant ships themselves. Enlarged full-resolution sections of the whole images highlighted in Fig. 3 show that in the original images some false targets are detected, which are eliminated in the filtered image.

IV. Conclusions

In this paper, a classical dual-use application, i.e., coastal area monitoring, is considered by using SAR data of the dual-use Italian Cosmo/Skymed satellite SAR constellation. In particular, improvements in the use of standard algorithms have been demonstrated, due to the use of a pre-processing step in which the AM&SF azimuth ambiguity filtering algorithm, recently proposed by the authors. Cosmo/Skymed stripmap SAR images of the area of the Gulf of Naples and of a sea area close to Malta have been here considered as first examples.

References

[1] R. K. Raney and G. J. Princz, “Reconsideration of Azimuth Ambiguities in SAR,” *IEEE Trans. Geosci. Remote Sens.*, vol. 25, no. 6, pp. 783–787, Nov. 1987.

[2] G. Di Martino, A. Iodice, D. Riccio, G. Ruello, "Filtering of Azimuth Ambiguity in Stripmap Synthetic Aperture Radar Images", *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol.7, no.9, pp. 3967-3978, 2014.

[3] A. Monti Guarnieri, “Adaptive Removal of Azimuth Ambiguities in SAR Images,” *IEEE Trans. Geosci. Remote Sens.*, vol. 43, no. 3, pp. 625–633, Mar. 2005.

[4] D. J. Crisp, “The state-of-the-art in ship detection in synthetic aperture radar imagery,” Intell., Surveillance and Reconnaissance Div., Inf. Sci. Lab., Def., Sci. Technol. Org., Edinburgh, S.A., Australia, May 2004, Res. Rep. DSTO-RR-0272.

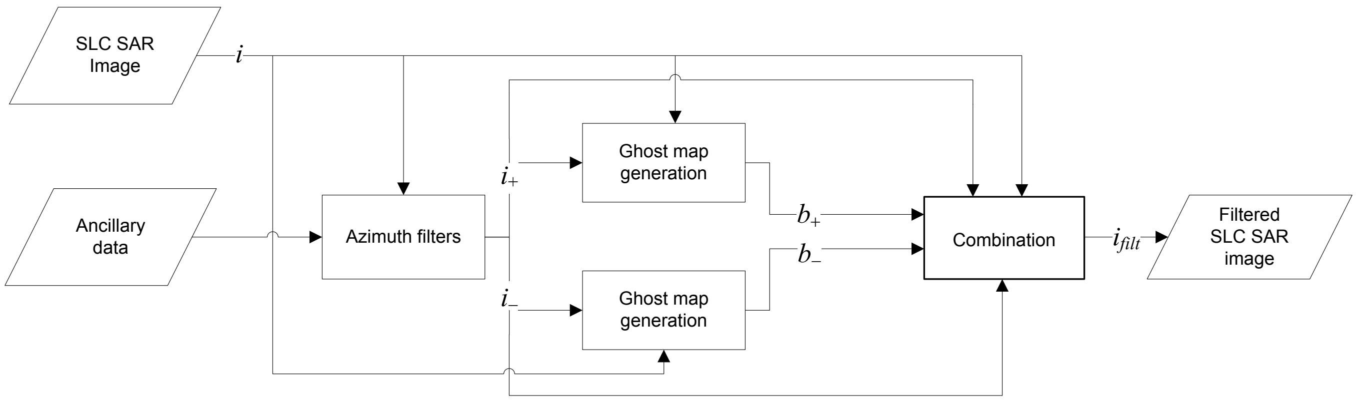

Fig. 1: Block scheme of the AM&SF azimuth ambiguity filtering approach. Here, i_+ and i_- are the images filtered via the filter relative to the right and left sidelobes, respectively, and b_+ and b_- are the corresponding "ghost" binary maps.

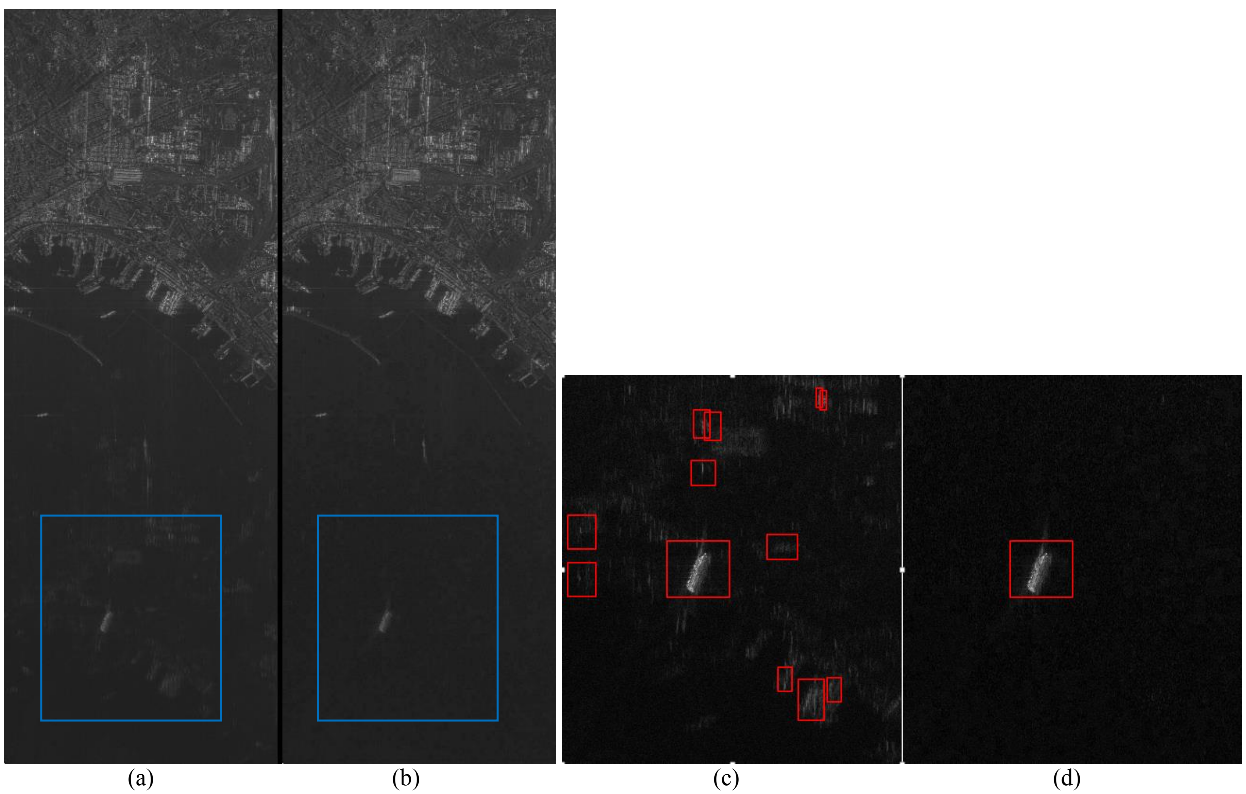

Fig. 2: Cosmo/Skymed image of the Gulf of Naples (Italy) before (a) and after (b) filtering. Full-resolution enlarged sections relevant to the area enclosed in blue squares are reported in (c) for the unfiltered image, and in (d) for the filtered one. Red rectangles indicate the objects identified as "ships" by the employed ship-detection algorithm.

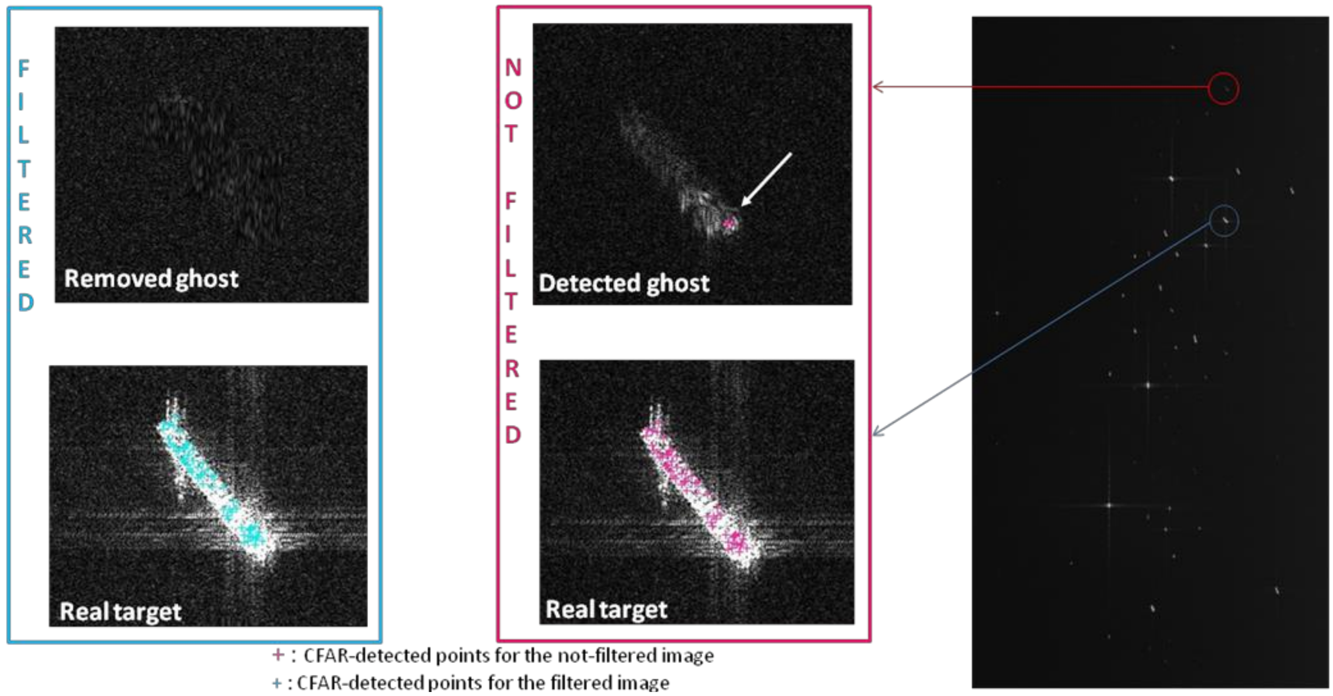

Fig. 3: Cosmo/Skymed image of a sea area near the coast of Malta. Full-resolution enlarged sections relevant to the areas enclosed in circles are reported on the right for the unfiltered image, and on the left for the filtered one. Colored crosses indicate the pixels identified as belonging to "ships" by the employed ship-detection algorithm.

978-1-5090-1131-5/16/$31.00 ©2016 IEEE